Title:

Quadrature Phase Shift Interferometer with Unwrapping of Phase

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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of United States provisional Patent Application, application number 60/312,152, filed August 14, 2001, which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0002] The present invention generally relates to interferometry, and more particularly to a quadrature phase shift interferometer.

BACKGROUND OF THE INVENTION

[0003] A form of an information storage and retrieval device is a hard disc drive [hereinafter "disc drive"]. A disc drive is conventionally used for information storage and retrieval with computers, data recorders, redundant arrays of independent discs (RAIDs), multi-media recorders, and the like. A disc drive comprises one or more disc media.

[0004] Each disc medium comprises a substrate upon which materials are deposited to provide a magnetically sensitive surface. In forming a disc medium, a substrate is ground or polished, conventionally by chemical-mechanical or mechanical polishing, to provide a substantially planar surface. Layers of materials are

substantially uniformly deposited on this substantially planar surface to provide magnetic properties for writing to and reading from the disc media.

[0005] However, defects, such as pits, voids, particles, bumps, and scratches, among others may arise on a disc medium surface. These defects need to be detected and characterized. Interferometers can be used to detect and characterize such defects. Displacement demodulation is conventionally done by counting fringes or demodulating phase. However, such interferometers have a relatively large number of optical components, as may be seen in U.S. Pat. No. 5,999,261.

[0006] Accordingly, it would be desirable to provide a method and apparatus for interferometry with a relatively small number of optical components to reduce optical path variation due to air turbulence, as well as to reduce energy loss due to ghost images reflected from optical component surfaces. Moreover, by providing an interferometer with a relatively small number of optical components, stability and immunity to thermal expansion and environmental vibration may be enhanced while cost is reduced.

SUMMARY OF THE INVENTION

[0007] The present invention provides method and apparatus for inspecting a disc medium surface. More particularly, a quadrature phase shift interferometer designed to provide an optical, non-contact testing method for inspecting a disc medium surface, or other surface, is described. Defects are detected and characterized by out-of-plane displacement. The interferometer described is able to measure out-of-plane displacements with nanometer resolution with frequency response in a range of DC to hundreds of mega hertz depending on detector rise time. Such an interferometer comprises fewer optical components as compared with prior art interferometers of at least equivalent capability.

[0008] An aspect of the present invention is an interferometer for disc surface inspection. The interferometer comprises a laser configured to provide a linearly polarized laser beam, and a variable ratio beam splitter positioned to receive the linearly polarized laser beam and configured to split the linearly polarized laser beam into a reference beam and an object beam. The reference beam and the object beam are polarized beams with polarizations orthogonal to one another. A mirror is

positioned to reflect the reference beam back toward the variable ratio beam splitter to provide a reflected reference beam. The disc surface is positioned to reflect of the object beam back toward the variable ratio beam splitter to provide a reflected object beam. The variable ratio beam splitter is positioned to receive the reflected reference beam and the reflected object beam, and configured to combine the reflected reference beam and the reflected object beam to provide a combinative beam. A non-polarizing beam splitter is positioned to receive the combinative beam and configured to split the combinative beam into a first output beam and a second output beam. An adjustable quarter-wave plate is positioned to receive the first output beam and configured to introduce a phase shift between the reflected object beam portion of the first output beam and the reflected reference beam portion of the first output beam to provide a phase-shifted output beam. A first polarizer is positioned to receive the phase-shifted output beam and configured to assemble the phase-shifted output beam along a predetermined direction to provided a first assembled beam. A second polarizer is positioned to receive the second output beam and configured to assemble the second output beam along the predetermined direction to provide a second assembled beam. A first optical detector is positioned to receive the first assembled beam and configured to provide a first voltage proportional to change in intensity due to interference of the reflected object beam portion and the reflected reference beam portion of the first assembled beam, and a second optical detector is positioned to receive the second assembled beam and configured to provide a second voltage proportional to change in intensity due to interference of the reflected object beam portion and the reflected reference beam portion of the second assembled beam.

[0009] An aspect of the present invention is a method for media surface inspection. The method comprises of providing a linearly polarized laser beam. The linearly polarized laser beam is split into a reference beam and an object beam based on polarization. The reference beam is reflected from a mirrored surface to provide a reflected reference beam. The object beam is reflected from the medium surface to provide a reflected object beam. The reflected reference beam and the reflected object beam are combined to provide a combinative beam. The combinative beam is split into a first output beam and a second output beam based on amplitude. A phase-shift is introduced between the reflected object beam portion and the reflected reference beam portion of the first output beam to provide a phase-shifted output beam. The phase-

shifted output beam is assembled at an angle with respect to direction of polarization to provide a first assembled beam. The second output beam is assembled at the angle to provide a second assembled beam. Fringes of the first assembled beam are detected to provide a first voltage, and fringes of the second assembled beam are detected to provide a second voltage.

[0010] Another aspect of the present invention is a method for inspection of a disc medium surface. The method comprises determining a first intensity for a first beam voltage, determining a second intensity for a second beam voltage, determining a first phase angle for the first intensity, determining a second phase angle for the second intensity, adding positive and negative values of a constant to the first phase angle and the second phase angle in response to slope direction of the first phase angle and the second phase angle to provide a phase function, and determining displacement caused by variations in the disc media surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the above recited features, advantages and objects of the present invention are attained and can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings.

[0012] It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0013] Fig. 1 is an optical layout of an exemplary portion of an embodiment of an interferometer in accordance with one or more aspects of the present invention.

[0014] Fig. 2 is a block diagram of an exemplary portion of an embodiment of an information processing system configured to receive light intensity voltage signals in accordance with one or more aspects of the present invention.

[0015] Fig. 3 is a signal graph of an exemplary portion of embodiments of phase versus temporal variation in light intensity normalized waves in accordance with one or more aspects of the present invention.

[0016] Fig. 4A is a signal graph of an exemplary portion of an embodiment of time versus normalized amplitude of *I* and *Q* waves as a function of phase in accordance with one or more aspects of the present invention.

[0017] Fig. 4B is a signal graph of an exemplary portion of an embodiment of time versus phase for wrapped phase wave in accordance with one or more aspects of the present invention.

[0018] Fig. 4C is a signal graph of an exemplary portion of an embodiment of time versus displacement for unwrapped phase wave in accordance with one or more aspects of the present invention.

[0019] Fig. 5 is a flow diagram of an exemplary embodiment of a program for disc media inspection in accordance with one or more aspects of the present invention.

[0020] While foregoing is directed to the preferred embodiment of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

DETAILED DESCRIPTION OF THE DRAWINGS

[0021] Fig. 1 is an optical layout of an exemplary portion of an embodiment of an interferometer system 50 in accordance with one or more aspects of the present invention. As will be understood, interferometer system 50, or more particularly quadrature phase shift interferometer 45, uses two polarization processes to create two independent interference signals, which are phase shifted with respect to one another. The presence of two independent signals in phase quadrature facilitates unwrapping of phase.

[0022] With continuing reference to Fig. 1, laser or laser beam source 20 is configured to provide a laser or other optical energy beam 21. Laser 20 may be configured to provide a linearly polarized laser beam. For example, a Helium-Neon (He-Ne) laser may be used, though it should be understood that the present invention may be used with known lasers of other wavelengths. Laser beam 21 is a linearly polarized laser beam. Laser beam 21 is provided to variable ratio beam splitter 49.

[0023] Variable ratio beam splitter 49 comprises a polarizing beam splitter (PBS) 25 and half-wave plate (HWP) 22. Notably, half-wave plate 22 is configured to rotate. By rotating half-wave plate 22, relative intensity or amplitude of reference beam 26 and object beam 27 may be adjusted. Half-wave plate 22 is used to rotate direction of polarization of laser beam 21 with respect to polarizing beam splitter 25. In other words, direction of orientation is adjusted such that polarizing beam splitter receives components of s-polarization and p-polarization. Laser beam 21 is provided to half-wave plate 22 and then to polarizing beam splitter 25. Polarizing beam splitter 25 splits laser beam 21 into a reference beam 26 and an object or measurement beam 27 according to s-polarization and p-polarization components. An aspect of the present invention is to balance intensity of reference beam 26 and object beam 27. Alternatively, half-wave plate 22 may be removed and direction of polarization controlled by rotation of laser 20.

[0024] Reference beam 26 and object beam 27 are polarized beams with polarizations perpendicular or orthogonal to one another. Thus, reference beam 26 may comprise only the s-polarized component of laser beam 21 and object beam 27 may comprise only the p-polarized component. Notably, reference beam 26 and object beam 27 are interchangeable.

[0025] Reference beam 26 is provided to quarter-wave plate (QWP) 28 and then to mirror 31. Reference beam 26 enters a passive side of quarter-wave plate 28. Reference beam 26 is reflected off an optically reflective surface of mirror 31 to provide reflected reference beam 30, as shown with a dashed line. For purposes of clarity, beams post-reflection and pre-recombination are shown with a dashed line.

[0026] Reflected reference beam 30 is provided to quarter-wave plate 28. Quarter-wave plate 28, as well as quarter wave-plate 29, are used to reduce power loss due to subsequent combination of reflected reference beam 30 and reflected object beam 31, respectively. Reference beam 26 immediately prior to passing through quarter-wave plate 28 comprises only linear polarization, namely s-polarization, components. After passing through quarter-wave plate 28, reference beam 26 linear polarization components are converted to circular polarization components. Reflected reference beam 30 immediately prior to passing through quarter-wave plate 28 comprises only circular polarization components. After passing through quarter-wave

plate 28, reflected reference beam 30 circular polarization components are converted to linear polarization, namely p-polarization, components, and thus reflected reference beam with p-polarization components passes straight through polarizing beam splitter 25 for providing a portion of combinative beam 33.

[0027] Object beam 27 is provided to a passive side of quarter-wave plate 29 and then to lens 46. Lens 46 is used to reduce spot size of object beam 27 for imaging off of surface 32 of disc medium 10. Spot size determines resolution for inspection purposes, and thus a smaller spot size allows smaller defects to be resolved. Focused object beam 27 from lens 46 leaves interferometer system 50 and then is reflected from surface 32 to re-enter interferometer system 50 back to lens 46, where it is reset to approximately the same spot size prior to focusing. Disc 10 is a moving, such as rotating, target. From lens 46, reflected object beam 31 is provided to quarter-wave plate 29. Object beam 27 immediately prior to passing through quarter-wave plate 29 comprises only p-polarization components. After passing through quarter-wave plate 29, object beam 27 comprises only circular polarization components. Reflected object beam 31 immediately prior to passing through quarter-wave plate 29 comprises only circular polarization components. After passing through quarter-wave plate 29, reflected object beam 31 comprises only s-polarization components, and thus as reflected object beam 31 enters from a side opposite to that of original entry to polarizing beam splitter 25, it is orthogonally diverted by polarizing beam splitter 25 in a direction opposite to that of reference beam 26 for providing a portion of combinative beam 33.

[0028] Notably difference in optical path length 48 and optical path length 47 is less than laser beam coherence length. Furthermore, it should be understood that surface defects on surface 32 causes displacement in optical path length 48. For example depending on reference level, a depression lengthens optical path length 48, both with respect to object beam 27 and reflected object beam 31, while a bump shortens optical path length 48. Maximum allowed displacement is limited by focus depth of lens 46. Optical path length 48 is modulated by surface 32, if surface 32 is moving. Optical path length 48 is modulated by out-of-plane, or more particularly out-of-reference plane, movement of surface 32.

[0029] Reflected reference beam 30 and reflected object beam 31 are combined

by polarizing beam splitter 25 to provide combinative beam 33. Combinative beam 33 comprises a reflected reference beam portion and a reflective object beam portion, as respective polarization directions of these portions are orthogonal. In other words, the reflected reference beam portion and the reflective object beam portion in combinative beam 33 do not interfere with one another.

[0030] Combinative beam 33 is provided from polarizing beam splitter 25 to non-polarizing beam splitter 34 (NPBS). Non-polarizing beam splitter 34 amplitude splits combinative beam 33 into output beam 23 and output beam 24.

[0031] One of output beam 23 or 24 is provided to a quarter-wave plate. In the embodiment shown in Fig. 1, output beam 23 is provided to quarter-wave plate 35. Quarter-wave plate 35 introduces a phase shift between reflected reference and reflected object beam portions or components of output beam 23. Quarter-wave plate 35 may be adjustable. Thus, for example, quarter-wave plate 35 could be adjusted, as needed, to introduce a target phase shift, for example approximately 90 degrees, between reflected reference and reflected object beam components of output beam 23. As described in more detail below, because two waves phase shifted with respect to one another are used, unwrapping of phase is facilitated. Such a phase shift is used for providing a quadrature output, as stated above. However, if outputs were viewed only in parallel, then quarter-wave plate 35 may be omitted. Notably, reflected reference and reflected object beam components of output beam 23, or output beam 24 for that matter, are still orthogonally polarized with respect to one another.

[0032] Polarizer 36 receives phase-shifted output beam 23 and assembles its reflected reference and reflected object beam components along a predetermined direction, for example approximately 45 degrees, to the vertical and horizontal axes of polarization of such components to provide assembled beam 38. As mentioned above HWP 22 is used to balance the beams, but if such beams were out of balance, a predetermined direction or angle may be selected or adjusted to enhance contrast of the interference. So, if reflected object and reference beam components are out of balance, then another angle may be selected to enhance the contrast by equalizing contributions of each such component in assembly of assembled beam 38. Assembled beam 38 may have interference between assembled reflected reference and reflected object beam components in response to displacement in optical path length 48 caused

by surface defects or other surface inconsistencies, or from a nominal surface condition depending on reference plane selection, as mentioned above.

[0033] Polarizer 37 receives output beam 24 and assembles its reflected reference and reflected object beam components along a predetermined direction, for example approximately 45 degrees, to the vertical and horizontal axes of polarization of such components to provide assembled beam 39. Assembled beam 39 may have interference between assembled reflected reference and reflected object beam components in response to displacement in optical path length 48 caused by surface defects or other surface inconsistencies, or from a nominal surface condition, as mentioned above.

[0034] Assuming surface defects exist and are detected, reflected reference and reflected object beam components interfere in assembled beams 38 and 39 to produce moving fringes representing modulation of optical path length 48. Such moving fringes, which are temporal variation in light intensity, may be observed in both output beams 38 and 39 in parallel. Alternatively, such moving fringes may be observed in both assembled beams 38 and 39 in parallel and in phase quadrature, as described in more detail in U.S. Pat. No. 5,999,261.

[0035] Assembled beams 38 and 39 are provided to optical detectors 40 and 41, respectively. Optical detectors 40 and 41 may be photodiode detectors. Detectors 40 and 41 operate at a speed sufficient to capture fringes from assembled beams 38 and 39 and deliver respective voltages proportional to temporal light intensity change as signals 43 and 44, respectively, for subsequent digital signal processing by information processing system (ISP) 42.

[0036] Referring to Fig. 2, there is shown a block diagram of an exemplary portion of an embodiment of an information processing system 42 configured to receive light intensity voltage signals 43 and 44 in accordance with one or more aspects of the present invention. Information processing system comprises processor 53, memory 54, input/output interface 55 and display device 56. Information processing system 42 may be a programmed personal computer or a digital oscilloscope or other known device for processing signals of the form of signals 43 and 44.

[0037] Signals 43 and 44, as mentioned above, represent temporal interference

fringes formed in response to temporal phase difference, $\emptyset$, between reflected reference beam 30 and reflected object beams 31. Temporal phase difference or phase, $\emptyset$, is a function of object displacement, d, namely displacement caused by disc medium surface 32. This relationship may be expressed as,

$$\emptyset = (2 \pi d)/\lambda \quad (1)$$

where wavelength, λ, is wavelength of laser beam 21. Notice that if displacement, d, equals 0, then phase $\emptyset$ equals 0, or in other words disc medium surface 32 is flat, which may be taken as a reference location. However, it is not necessary to take the flat or unaffected portion of a disc media surface 32 as a reference location or plane. Accordingly, it should be understood that displacement, d, is a value depending on a reference location. Thus, displacement d is actually a change in displacement, Δd, with respect to such a reference location. Likewise, phase, $\emptyset$, is actually a change is phase, $\Delta \emptyset$, due to change in displacement.

[0038] Assuming interferometer system 50 is properly aligned and adjusted, intensity I received at optical detector 40 and intensity Q received at optical detector 41 may be represented as,

$$I = Ia + Ib \cos(\emptyset) \quad (2A)$$

$$Q = Qa - Qb \sin(\emptyset) \quad (2B)$$

where,

$$Ia = (Imax + Imin)/2 \quad (3A)$$

$$Ib = (Imax - Imin)/2 \quad (3B)$$

$$Qa = (Qmax + Qmin)/2 \quad (3C)$$

$$Qb = (Qmax - Qmin)/2 \quad (3D)$$

where *Imax* and *Imin* are the maximum and minimum intensities of the *I* beam, namely assembled beam 38, over a time period, and where *Qmax* and *Qmin* are the maximum and minimum intensities of the *Q* beam, namely assembled beam 39, over the time period. Conventionally, the time period for obtaining accurate maximum and minimum

intensities is in the range of approximately 10 to 20 cycles of the *I* or Q beam.

[0039] Because phase angle is used as the argument for a sine and a cosine function as in Equations (2A) and (2B) [collectively "Equations (2)"], phase wrapping occurs. In other words, phase wraps around to the same value for every 2π increase or decrease. To obtain the actual phase in Equation (1), phase from Equations (2) must be unwrapped. However, because phase Ø directly resolved from Equations (2) yield the principal value of phase, the first step of unwrapping phase is to calculate the phase angle and extend it into a 0 to 2π phase range. To calculate phase angle in a 0 to 2π phase range, phase is calculated according to rules or boundary conditions of Equations (4A) and (4B) for phase angle of assembled beam 38,

$$Ø = \text{cos-1}[(I-Ia)/Ib] \text{ for } Q-Qa0 \qquad (4A)$$

$$Ø = 2\pi - \text{cos-1}[(I-Ia)/Ib] \text{ for } Q-Qa>0 \qquad (4B)$$

and Equations (5A), (5B) and (5C) for phase angle of assembled beam 39,

$$Ø = \text{sin-1}[(Qa-Q)/Qb] \text{ for } I-Ia0 \text{ and } Q-Qa0 \qquad (5A)$$

$$Ø = \pi - \text{sin-1}[(Qa-Q)/Qb] \text{ for } I-Ia<0 \qquad (5B)$$

$$Ø = 2\pi + \text{sin-1}[(Qa-Q)/Qb] \text{ for } I-Ia0 \text{ and } Q-Qa>0 \qquad (5C)$$

[0040] Fig. 3 is a signal graph of an exemplary portion of embodiments of phase versus *I* and Q normalized waves 61 and 62, respectively, in accordance with one or more aspects of the present invention. For purposes of clarity, *I* and Q waves have been normalized to have amplitude of plus or minus one and $Ia = Qa = 0$. From Fig. 3, it may be seen that when $Q < 0$ or $Q > 0$, phase of *I* wave 61 is only within the range of 0 to π or π to 2π, respectively, namely, respectively Equations (4A) and (4B) [collectively "Equations (4)"] and their respective conditions provide phase angle for *I* wave 61. Phase angle for Q wave 62 is determined by Equations (5A), (5B), and (5C) [collectively "Equations (5)"] and their respective conditions. When $I < 0$, phase of Q wave 62 is with the range of $\pi/2$ to $3\pi/2$, namely, Equation (5B). However, an arbitrary situation occurs while $I > 0$, as phase of Q wave 62 can be either in the range of 0 to $\pi/2$ or the range of $3\pi/2$ to 2π. This is resolved by using the value of Q wave 62 as an additional condition. If $I > 0$ and $Q < 0$, phase of Q wave 62 is within the range of 0 to

$\pi/2$, namely, Equation (5A); and if $I > 0$ and $Q > 0$, phase of Q wave 62 is within the range of $3\pi/2$ to 2π, namely, Equation (5C).

[0041] As a practical matter, phase angle resolved from Equations (4) and Equations (5) may not be the same. This is due in part to use of trigonometric functions in Equations (4) and (5), and this is due in part to sensitivity of intensities as a function of phase location, namely, change of phase $\varnothing$ effect on I and Q. In Equations (4), I is most sensitive to phase change when phase angle is approximately $\pi/2$ or $3\pi/2$ and is least sensitive when phase angle is approximately 0 or π. In contrast, in Equations (5), Q is least sensitive to phase change when phase angle is approximately $\pi/2$ or $3\pi/2$ and is most sensitive when phase angle is approximately 0 or π. This non-linearity reduces accuracy in phase angle calculation.

[0042] To improve accuracy in phase angle calculation, a weighted average of phase angles calculated from Equations (4) and (5) may be used. An example of such a weighted average is,

$$\varnothing AVG = W(\varnothing)\varnothing 1 + [1 - W(\varnothing)]\varnothing 2 \qquad (6)$$

where, $\varnothing 1$ and $\varnothing 2$ are phase angles calculated from Equations (4) and (5), respectively, and where $W(\varnothing)$ is a weight factor. $W(\varnothing)$ is preferably a function of a trigonometric function. For example, $W(\varnothing)$ may be,

$$W(\varnothing) = \cos[(\varnothing 1/2) + (\varnothing 2/2)] \qquad (7)$$

Notably, a more complex weight factor than that of Equation (7) may be used, in particular a weight factor derived by experiment based on an actual system set up.

[0043] Referring to Fig. 4A, there is shown a signal graph of an exemplary portion of an embodiment of time versus normalized amplitude of I and Q waves 61 and 62, respectively, as a function of phase in accordance with one or more aspects of the present invention. This embodiment is for disc run-out of a disc; however, other features of a disc may be measured. I and Q waves of Fig. 4A may be described by Equations (2) using signals 43 and 44 and phase conditions from Equations (4) and (5).

[0044] Referring to Fig. 4B, there is shown a signal graph of an exemplary

portion of an embodiment of time versus phase for wrapped phase wave 63 in accordance with one or more aspects of the present invention. From *I* and *Q* waves of Fig. 4A and from Equations (4) and (5), wrapped phase wave 63 is determined. Results from Equations (4) and (5) are wrapped phase at multiples of 2π, as illustratively shown in Fig. 4B.

[0045] Referring to Fig. 4C, there is shown a signal graph of an exemplary portion of an embodiment of time versus displacement for unwrapped phase wave in accordance with one or more aspects of the present invention. Constants of plus or minus $2n\pi$, for n a positive number, are added to phase values in wrap regions, such as from Fig. 4B, to form a continuous phase function, namely unwrapped phase wave, which is proportional to displacement wave 64. Sign of $2n\pi$ is determined by the direction of phase stepping. If slope of phase from wrapped phase wave 63 of Fig. 4B is positive, then a $+2n\pi$ is used. If slope of phase from wrapped phase wave 63 of Fig. 4B is negative, then a $-2n\pi$ is used. In other words, if phase jumps from 0 to 2π, a minus sign applies to $2n\pi$; otherwise, if phase jump is from 2π to 0, a plus sign applies to $2n\pi$. After adding such constants of plus or minus $2n\pi$ to phase values of Fig. 4B, displacement may be calculated using a variation of Equation (1), namely,

$$d = (\varnothing AVG \cdot \lambda)/(2\pi) \qquad (8)$$

to provide time versus displacement as shown in Fig. 4C.

[0046] Referring to Fig. 5, there is shown a flow diagram of an exemplary embodiment of a program 70 for disc media surface inspection in accordance with one or more aspects of the present invention. Information processing system 42 of Fig. 2 may be programmed with program 70 or may be coupled to a network 57, such as a portion of an intranet or the Internet. At step 71, a first intensity is determined for a first beam voltage, such as voltage on signal 43. At step 72, a second intensity is determined for a second beam voltage, such as voltage on signal 44. At step 73, a first phase angle is determined as associated with the first intensity. At step 74, a second phase angle is determined as associated with the second intensity. At step 75, positive and negative values of a constant are added to the first phase angle and the second phase angle, or a weighted average phase angle therefrom. Whether a positive or a negative value of the constant is used is determined in response to phase angle slope,

such as slope of the first phase angle, slope of the second phase angle or slope of the weighted average phase angle. At step 76, displacement caused by the disc media surface is determined.

[0047] An embodiment of the present invention is implemented as a program product for use with a information processing system such as, for example, information processing system 42 of Fig. 2. The program(s) of the program product defines functions of the embodiments and can be contained on a variety of signal-bearing media, which include, but are not limited to: (i) information permanently stored on non-writable storage media (*e.g.*, read-only memory devices within a computer such as CD-ROM discs readable by a CD-ROM drive); (ii) alterable information stored on writable storage media (*e.g.*, discs within a floppy drive or hard disc drive); or (iii) information conveyed to a computer by a communications medium, such as through a computer or telephone network, including wireless communications. The latter embodiment specifically includes information downloaded from the Internet and other networks. Such signal-bearing media, when carrying computer-readable instructions that direct the functions of the present invention, represent embodiments of the present invention.

[0048] While foregoing is directed to the preferred embodiment of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.